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Associations among behavioural inhibition and owner-rated attention, hyperactivity/impulsivity, and personality in the domestic dog (*Canis familiaris*)

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Contributions

NB: Conceptualization, Formal Analysis, Writing – Original Draft, Writing – review and Editing, Visualization
BCS: Conceptualization, Methodology, Investigation, Writing – review and Editing, Project Administration
CSP: Investigation, Software, Writing – review and Editing,
BF: Software, Writing – review and Editing,
ÁM: Writing – review and Editing, Funding Acquisition
MG: Conceptualization, Methodology, Resources, Writing – review and Editing, Supervision, Funding Acquisition

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Abstract

In humans, behavioural disinhibition is associated with attention-deficit/hyperactivity disorder (ADHD). Limitations to rodent models of ADHD-like behaviours/symptoms (ADHD-B/S) may be augmented by complementary ones, such as the domestic dog. We examined associations between family dogs' (*N*=29; of 14 breeds and 12 mongrels) performance on a self-developed touchscreen behavioural Go/No-Go paradigm and their owner-rated inattention (IA) and hyperactivity/impulsivity (H/I), accounting for relevant covariates. A greater proportion of commission errors was associated with greater H/I. Regardless of accuracy, relative to dogs with no prior training, those with basic training had shorter response latencies. Also regardless of accuracy, greater confidence and extraversion were associated with shorter latencies, and greater openness was associated with longer latencies. Shorter latency to commission errors was associated with greater IA. Findings support the dog as a model of the association between behavioural inhibition and ADHD-B/S and are early evidence of convergent validity between the behavioural paradigm and the rating scale measure in dogs.

Keywords: behavioural inhibition, inattention, hyperactivity/impulsivity, domestic dog, Go/No-Go test

Associations among behavioural inhibition and owner-rated attention, hyperactivity/impulsivity, and personality in the domestic dog (*Canis familiaris*)

In the cognitive- and/or neuropsychology literatures, behavioural or response inhibition is the ability to suppress actions that are inappropriate or undesirable, given short-term adaptation and long-term goals (Barkley, 1997; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Nigg, 2001). Specifically, behavioural inhibition is definable as "three interrelated processes: (a) inhibition of an initial, prepotent response to an event (inhibitory control); (b) stopping of an ongoing response, which thereby permits a delay in the decision to respond; and (c) the protection of this period of delay and the self-directed responses that occur within it from disruption by competing events and responses (interference control)" (Barkley, 1997; p. 67). The first two of these processes are also referred to as action restraint and action cancellation. The former is typically probed in tasks such as the go/no-go paradigm, with the ability or failure to withhold from responding as the outcome of interest (indexed by, e.g., percentage of successful inhibition and commission errors, etc.). The latter is typically studied using the stop-signal task, with the ability or failure to inhibit a motor response *during* its execution as the outcome of interest (Eagle, Bari, & Robbins, 2008).

A large body of work indicates that deficient behavioural or response inhibition (hereafter: behavioural inhibition) is a predisposing or risk factor for a range of psychological and psychiatric disorders and negative outcomes. These include antisociality and disruptive behaviour (Nigg, 2003; Oosterlaan & Sergeant, 1998; Swann, Lijffijt, Lane, Steinberg, & Moeller, 2009; Young et al., 2009), alcohol and other drug misuse and dependence (Iacono, Malone, & McGue, 2008; Nigg et al., 2006), borderline (Nigg, Silk, Stavro, & Miller, 2005) and obsessive-compulsive traits (Bannon, Gonsalvez, Croft, & Boyce, 2002), as well as parent- and teacher-rated social impairment in children (Bunford et al., 2015). Behavioural inhibition

88 has perhaps been most often linked to attention-deficit/hyperactivity disorder (ADHD)
89 (Barkley, 1997; Bunford et al., 2015).

90 Although ADHD incidence rates have increased, treatments have not correspondingly
91 advanced, potentially due to lack of appropriate animal models (Majdak et al., 2016). Several
92 animal – primarily rodent – models of ADHD – or, most appropriately, *ADHD-like behaviours*
93 *and symptoms* (hereafter: ADHD-B/S) (Sontag, Tucha, Walitza, & Lange, 2010) – have been
94 proposed and these range from ones with genetic manipulation to neurotoxic lesions (Sontag
95 et al., 2010). Although there is ample research on behavioural disinhibition (Kolokotroni,
96 Rodgers, & Harrison, 2011; Morgan, Einon, & Nicholas, 1975) and ADHD-B/S in rodents
97 (Adriani, Caprioli, Granstrem, Carli, & Laviola, 2003; Sagvolden et al., 2009), with results
98 generally indicating similar cognitive and neuropsychological mechanisms connecting these
99 phenomena as in humans (Fox, Hand, & Reilly, 2008), there are limitations to the rodent model.

100 For example, the dopamine transporter (DAT) knock-out mouse exhibits
101 neurochemical alterations irrelevant for modelling classical ADHD (Gainetdinov, 2010).
102 Spontaneously hypertensive rats (SHR) exhibit hypertension as a confounding factor
103 (Sagvolden, Russell, Aase, Johansen, & Farshbaf, 2005) and high levels of on-task behaviour
104 in fixed-interval/extinction paradigms despite clinical characterization of inattention
105 emphasizing off-task behaviour and distractibility (Alsop, 2007). Generally, rodents need fluid
106 and/or food restriction as a motivational tool relative to human voluntary participation and are
107 kept in a restricted laboratory environment as living space relative to the complex and variable
108 environment of human living spaces. These limit generalizability of rodent data.

109 A novel and promising animal model of human behaviour and cognition is the domestic
110 dog (*Canis familiaris*). First, dogs are interesting – in some aspects uniquely so – from an
111 ethological, comparative psychological perspective as certain adaptational processes during
112 their domestication have shaped their behavioral and socio-cognitive skills in a manner that

they are exceptionally able and motivated to competently interact with humans (Topál, Miklósi, et al., 2009). While in rodents most social interactions center around dominance, reproduction, and parental care, an evolutionarily new behavioral regulation system, one that organizes their social behaviors towards/with humans, has developed in dogs.

This makes the dog an ideal animal model of complex human processes, including cognitive and social ones. In support is a long line of research focused on phenomena related to canine behavior, cognition, and emotion, such as inequity aversion (Range, Horn, Viranyi, & Huber, 2009), automatic (Range, Huber, & Heyes, 2011) and selective imitation (Range, Viranyi, & Huber, 2007), reward processing (Gerencsér, Bunford, Moesta, & Miklósi, 2018), comprehension of pointing gestures (Lakatos, Soproni, Dóka, & Miklósi, 2009), and social referencing (Merola, Prato-Previde, & Marshall-Pescini, 2012). Further, dogs have been shown to exhibit spontaneous affiliative responses to human social stimuli, including in terms of attachment (Gácsi, Topál, Miklósi, Dóka, & Csányi, 2001) as well as preferential attention to the eyes of humans and early and specific sensitivity to establishing eye contact with humans (Gácsi et al., 2005), compulsory compliance in social situations (Topál, Gergely, Erdöhegyi, Csibra, & Miklósi, 2009), and an ability to adapt emotionally and physiologically to humans (indicated by emotional contagion; Sümegi, Olah, & Topál, 2014). Recently, in combination with or without behavioral approaches, neuroscience methods are used to study awake dog behavior, including reward-, visual- and vocal processing (e.g., Andics et al., 2016; Andics, Gácsi, Faragó, Kis, & Miklósi, 2014), memory consolidation (Kis et al., 2017) as well as canine sleep (e.g., Bunford et al., 2018; Iotchev, Kis, Bódizs, Van Luijtelaar, & Kubinyi, 2017; Kis et al., 2014; for review, see Bunford, Andics, Kis, Miklósi, & Gácsi, 2017).

With regard to ADHD B/S, dogs are a promising species for comparative research insofar as individual variation in these observable characteristics, if analogous to those observed in humans, would suggest that the observed phenotypic variability not only parallels

human behavior but is also relevant to better understanding the underlying genotypic or biological variability. In this vein, dogs exhibit behaviors redolent of the repetitive and stereotyped behaviors observed in youth with autism spectrum disorders, and the molecular background of these behaviors is similar in the two species (Tsilioni et al., 2014). Researchers have also identified canine genes for characteristics relevant to agility (Kim & Davis, 2018), friendliness (VonHoldt et al., 2017), attachment (Kovács et al., 2018) and social behavior (Kis, Bence, et al., 2014). As such, identification of further phenotypic parallels, including in inhibition, may clarify the genetic basis of ADHD/BS not only in humans but also in dogs.

Second, dogs are interesting given their potential value as a model of human clinical conditions, including ADHD B/S. Because dogs naturally exhibit (unlike rodents; Hejjas et al., 2007) individual differences in inhibition and ADHD-B/S (Vas, Topál, Pech, & Miklósi, 2007; Wright, Mills, & Pollux, 2011, 2012) and genetic polymorphisms relevant to ADHD-B/S (Wan et al., 2013), their biological manipulation is unnecessary. Further, as dogs exhibit socio-cognitive skills that share behavioural and functional characteristics with humans' (Miklósi & Topál, 2013) and dogs share their physical and social environment with humans, they are a suitable model for testing not only differences in ADHD-B/S but also relevant functional outcomes (e.g., socio-cognitive skill deficits and social impairment; Bunford et al., 2015). More generally, dogs' cooperativeness and trainability obviate the need for fluid and/or food restriction, allowing them to have a physiological and social state in experiments comparable to humans'. Indeed, behavioural paradigms (e.g., Topál, Miklósi, Csányi, & Dóka, 1998) and rating scales (Lit, Schweitzer, Iosif, & Obermauer, 2010; Vas et al., 2007; Wright et al., 2012) designed to assess human behaviour have been adapted to measure dog behaviour.

Studies on canine inhibition assess a characteristic related to behavioural inhibition, cognitive inhibition, i.e., ability to tolerate delayed gratification (Riemer, Mills, & Wright, 2014; Wright et al., 2012). Similarly to humans, canine intolerance of delayed gratification is

stable (Riemer et al., 2014), and higher owner-rated impulsivity is associated with behavioural manifestation of intolerance of delayed reward (Wright et al., 2012). Available studies on differences in canine inattention (IA) and hyperactivity/impulsivity (H/I) rely solely on rating scales and there are no studies on individual differences in canine *behavioural* inhibition and its relation to ADHD-B/S.

To study these relationships in humans, behavioural paradigms of inhibition are typically paired with rating scale measures of ADHD symptoms (e.g., Bunford et al., 2015). One of the most commonly used of such paradigms is the Go/No-Go task (Votruba & Langenecker, 2013). Youth with ADHD, relative to typically developing peers, consistently exhibit more errors and slower response times on Go/No-Go tasks (Castellanos, Giedd, Hamburger, Marsh, & Rapoport, 1996; Hartung, Milich, Lynam, & Martin, 2002; Vaidya et al., 1998). Omission errors (when a behavioural response should be executed but is not) are primarily associated with IA whereas commission errors (when a behavioural response should not be executed [i.e., should be inhibited] but is) are primarily associated with H/I (Bezdjian, Baker, Lozano, & Raine, 2009; Trommer, Hoeppner, Lorber, & Armstrong, 1988). As such, the Go/No-Go task is relevant to probing behavioural inhibition and to assessing the association between task performance and ADHD-B/S. It is ideal for comparative research as it is appropriate for assessment of human and animal subjects without considerable alterations to experimental or task design (Eagle, Bari, et al., 2008).

Differences in personality in both humans and in animals (including rodent models of ADHD), are associated with differences in behavioural inhibition and/or ADHD; and, as such, should be considered in designs involving these phenomena. For example, prior findings indicate that agreeableness and extraversion are negatively whereas neuroticism is positively associated with behavioural inhibition (Muris et al., 2009). Also, although agreeableness (low) and neuroticism (low) are linked to ADHD, they are not specific to it (but are, rather, better

explained by comorbid psychopathologies) and the literature on the association between extraversion and ADHD is mixed (Nigg et al., 2002). Conversely, findings indicating that more severe ADHD symptoms are related to lower conscientiousness appear to reflect that this effect is unique to IA (Nigg et al., 2002) and is independent of co-occurring antisocial and delinquent behaviour (Nigg, Blaskey, et al., 2002). Similarly, increased aggression has been observed in association with behavioural disinhibition in the 5-HT1B serotonin receptor knockout mouse (Brunner & Hen, 1997; Nautiyal et al., 2015). Reduced levels of the serotonin metabolite 5-hydroxyindole acetic acid (5-HIAA) in mice (Caramaschi, de Boer, & Koolhaas, 2007) and primates (Mehlman et al., 1994) are associated with aggression and impulsivity. In fish and lizards, the onset of aggressive behavior is associated with increased serotonergic activity, whereas inhibition of aggression and social subordination are related to prolonged elevation of serotonin metabolism (Øverli, Harris, & Winberg, 2000; Stoddard, 2003; Summers et al., 2005). Finally, increased aggression and reactivity has been found in one rodent model of ADHD, the DAT knockout mouse (Rodriguiz, Chu, Caron, & Wetsel, 2004).

Current Study

Our primary aim in the current study was thus to examine associations among dogs' performance – as indexed by error rate and response time – on a self-developed touchscreen behavioural Go/No-Go test and their owner-rated IA and H/I and dimensions of personality on two widely-used rating scales, in an average population of animals (i.e., not selected for a certain level of inattention or hyperactivity/impulsivity).

Method

Participants and Procedures

Participants were 29 adult family dogs (M_{age} = 4.59 years, *SD* = 2.90) of 14 different breeds and 12 mongrels (3 intact female, 6 intact male, 13 spayed female, 7 neutered male). As the current study was the first of its kind, there were no prior data available to conduct a formal

power analysis and determine a necessary sample size. Our aim was thus to establish whether an effect of any magnitude can be demonstrated. The sample of 29 dogs allowed for simultaneously achieving feasibility in addressing our research questions and minimizing burden of participation in case of both owners and their dogs (who had to participate in training and testing, on average, on 18 occasions, see Canine Go/No-Go paradigm below). Differences in training status were indexed as "none" (no training), "basic" (basic obedience training), "intermediate" (higher level obedience training), or "advanced" (IPO Schutzhund, rescue, service, or gun dog exam) and thus reflected differences in both cognitive and physical training status. Seven dogs had none, 12 basic, 4 intermediate, and 6 advanced training. Owners and their dogs were recruited through the Department of Ethology participant pool and website, popular social networking sites, and via snowball sampling. All experimental procedures (training and test, see *Canine go/no-go paradigm below*) took place at the Eötvös Loránd University, Department of Ethology, in a 3 m × 6 m experimental room.

Measures

Canine Go/No-Go paradigm. In a basic sense (there are variations), Go/No-Go paradigms involve two types of stimuli presented in some modality, e.g., auditorily or visually: one stimulus, which is the "go" stimulus, is to be responded to with the execution of some form of action or behaviour. The other stimulus, which is the "no-go" stimulus, is to be responded to with the withholding of some form of prepotent action or behaviour. In case of the current study, corresponding details are described below.

Presentation and recording apparatus. Dogs were trained to use a touchscreen device. This comprised a 36 cm tall and 47 cm wide touchscreen (31.5 cm × 38.5 cm screen with a 1024 × 768 pixel resolution; ZYTRO-19; Novoparts, Budapest, Hungary) with integral mounting plates in the rear wall. The touchscreen was mounted to an 82 cm aluminium panel to offset it from the ground, with its height adjustable to the dog's height. An automatic feeder

was placed 2 m away from the touchscreen device (see Figure 1 for experimental setup). The touchscreen utilizes capacitive sensing to monitor and record touches. The Opensesame 3.0.7 software was used for stimulus presentation and response recording, with a dedicated Windows based PC for the testing room.

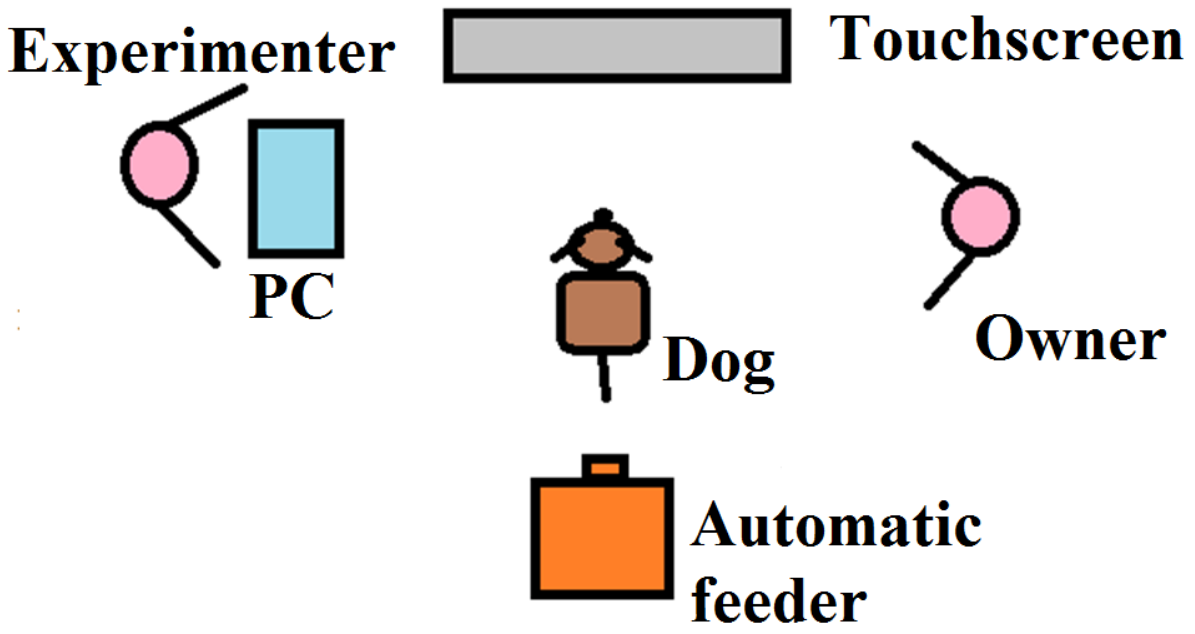

Figure 1. *Depiction of experimental setup showing location of experimenter, owner, dog, touchscreen device, and automatic feeder.*

Stimuli. Experimental stimuli were blue and yellow circles and triangles (with overall dimensions of 300 × 300 pixels). The colours blue and yellow were chosen because unlike humans, who have cone cells in their retina that are sensitive to three different types of colours (blue, green, and red), dogs have cone cells sensitive only to two colours (i.e., blue and yellow); as such, it is easiest for dogs to differentiate blue and yellow based on colour (as opposed to e.g., brightness) (Jacobs, Deegan, Crognale, & Fenwick, 1993).

An early comparison of stimuli groups (based on stimulus characteristics, i.e., colour and shape) indicated that neither colour, nor shape, nor the interaction between the two had an effect on dogs' performance (two-way ANOVA main and interaction effect *p*s > .328). Thus, dogs were randomly assigned to one of two groups to control for stimulus characteristic (colour

or shape) effects. For example, for one group, a yellow circle was the "go" stimulus and a blue triangle was the "no-go" stimulus whereas for another groups, a blue circle was the "go" stimulus and a yellow triangle was the "no-go" stimulus.

Training. Training for the Go/No-Go test consisted of three phases generally consistent with training for rodents (Levin & Buccafusco, 2006); during the first phase, which was a "go" training phase, dogs were presented only with their respective "go" stimulus and trained to respond to such stimulus by poking with or pressing their noses against it (hereafter: nose poke) on the touchscreen. Dogs were rewarded with a treat (mostly dry dog food but in some cases, when the dog had food allergies, a treat chosen by the owner was used, typically sausage) for every correct "go" response. Dogs moved on to the second training phase after they completed 2 sets of 20 stimuli one after another with at least 80% accuracy. On average, dogs completed the first phase in $M = 5.79$, $SE = 0.55$ sessions (range: 1-14).

During the second phase, which was a discrimination training phase, dogs were simultaneously presented with their respective "go" and "no-go" stimuli and trained to respond only to the "go" stimulus by executing a nose poke but not to the "no-go" stimulus. Dogs were rewarded with a treat for every correct "go" response but received no feedback for omission (not poking the "go" stimulus) or commission (poking the "no-go" stimulus) errors. Dogs moved on to the third training phase after they completed 2 subsequent sets of 20 stimuli with at least 80% accuracy. On average, dogs completed the second phase in $M = 4.17$, $SE = 0.34$ sessions (range: 2-8).

During the third and last phase, which was a "no-go" training phase, dogs were presented either with their respective "go" stimulus or with their "no-go" stimulus (50% "go" and 50% "no-go"). Stimuli were presented in a pseudo-random fashion, such that no more than two of the same type was presented following one another and the first and the second stimuli could not be the same. Regarding "go" stimuli, dogs continued to be rewarded for every correct "go"

response. Regarding "no-go" stimuli, dogs were rewarded for every correct "no-go" response, with the time between the stimulus onset and reward gradually increased up to 3 s. As such, consistent with other animal studies of go/no-go paradigms, dogs were rewarded with a treat for every correct "go" *and* "no-go" response (e.g., Matsumoto, Suzuki, & Tanaka, 2003; Tremblay & Schultz, 2000). Dogs moved on to the Go-No-Go test after they completed 2 subsequent sets of 20 stimuli with at least 80% accuracy. On average, dogs completed the third phase in $M = 8.14$, $SE = 1.05$ sessions (range: 1-24).

Test. The Go/No-Go test consisted of 2 sets of 20 stimuli (60% "go" and 40% "no-go"). *Note.* During training phase, a 50-50 ratio was employed to ensure feasibility of dogs learning the paradigm. While this 50-50 split was necessary for training purposes, it is generally not considered appropriate in case of Go/No-Go tests, as an underlying assumption in such tests is that one response is more automatic, i.e., prepotent and, as such, can be withheld only via recruitment of inhibitory functions and processes. For one response to be more automatic and prepotent, one stimulus, which is thus the "Go" stimulus, is presented more frequently than the "No-Go" stimulus. Although there is variability across prior studies in terms of the portion of "go" and "no-go" stimuli presented in Go/No-Go tests, in the current study, the 60-40 ratio was chosen based on pertinent literature (e.g., Liu et al., 2015). A correct "go" response indicated that the dog executed a nose poke within 3 s after stimulus onset and an omission error indicated that the dog did not execute a nose poke within 3 s. A correct "no-go" response indicated that the dog did not execute a nose poke within 3 s after stimulus onset and a commission error indicated that the dog did execute a nose poke within 3 s (see Supplement for an illustrative video clip of two dogs participating in the Go/No-Go test).

Rating scale measures. Dogs' owners were asked to complete questionnaires online that was comprised of the following rating scales and questions.

IA and H/I. Individual differences in IA and H/I were measured using the *Dog-ADHD Rating Scale* – Owner Version (Lit et al., 2010; Vas et al., 2007), which is a 13-item (6 items measuring IA and 7 items measuring H/I) owner-report measure of dogs' level of attention and hyperactivity/impulsivity. The measure was originally developed based on a well-validated and widely used parent-report rating scale measure of ADHD and related problems in children, the ADHD-RS-IV (DuPaul, 1998). Owners indicate the frequency with which their dog behaves as described in each item (ranging from 'never' to 'very often'). Initial examination of the measure's psychometric properties (with over 200 animals representing over 60 different dog breeds) indicated preliminary evidence for its internal consistency and external validity (i.e., age-, sex-, and training-based differences given rating scale scores) (Vas et al., 2007). Greater scores indicate greater difficulties with IA and H/I. In the current sample, the subscales exhibited acceptable internal consistency, with Cronbach's alphas (α) ranging from .60 to .88 and so did the total scale $\alpha = .84$.

Covariates of interest. Individual differences in personality were measured using the canine Big Five Personality Inventory (Gosling, Rentfrow, & Swann, 2003), which is a 43-item owner-report measure of dogs' personality. The questionnaire was originally developed based on the Big Five framework, an extensively researched and widely used model of personality. Owners indicate the degree to which (ranging from 'not at all' to 'extremely') each characteristic is true about their dog as described in each item. The measure has exhibited acceptable psychometric properties as indexed by internal consistency (Turcsán, Range, Virányi, Miklósi, & Kubinyi, 2012). In the current study, the five subscales, confidence (the opposite of neuroticism), conscientiousness, cooperation (comparable to agreeableness on the human Big Five), extraversion, and openness exhibited acceptable internal consistency (αs ranging from .60 to .74), except for conscientiousness, which had unacceptable internal consistency ($\alpha = .46$) and thus was not considered in the analyses.

Covariates of non-interest. Relevant covariates that have been previously hypothesized or shown to be associated with differences in canine IA and H/I, were dogs' owner-reported age, sex, and training status (Vas et al., 2007).

Ethical statement

Owners volunteered to participate in the behavioural paradigms with their dogs and completing the questionnaires and gave written consent. Non-invasive animal research is currently allowed without need for permission from the University Institutional Animal Care and Use Committee (UIACUC). A written statement (#PEI/001/3819-4/2015) was obtained from the Food Chain Safety and Animal Health Directorate Government Office based on the decision of the Scientific Ethic Council of Animal Experiments. According to this statement and the corresponding definition by law, the current non-invasive observational study is not an animal experiment.

Analytic Plan

SPSS V22.0.0.0 was used for all analyses. Descriptive statistics were calculated to characterize the sample on all dependent and independent variables as well as covariates. Dependent variables of interest were omission error percent (the proportion of omission errors relative to the total number of "go" stimuli), commission error percent (the proportion of commission errors relative to the total number of "no-go" stimuli), average latency of correct "go" responses (the time, in s, that has passed between stimulus onset and execution of a correct "go" response), and average latency of commission errors (the time, in s, that has passed between stimulus onset and execution of a commission error). Independent variables of interest were dogs' IA and H/I scores. Covariates of interest were dogs' personality dimension scores and co-variates of non-interest were age, sex, and training status.

To evaluate the effects of independent (IA and H/I) and covariate (personality, age, sex, and training status) variables on omission and commission error percent, multiple multivariate

linear regression analyses (using the SPSS GLM-multivariate option) with backward elimination were conducted, taking into consideration both significance level of individual predictors and model fit. To evaluate the effects of independent and covariate variables on latency of correct "go" and commission errors, survival analyses (i.e., Cox regression analysis with occurrence of a response as terminal event) with backward elimination were conducted, taking into consideration both significance level of individual predictors and model fit. Model assumptions were considered prior to (or following, where appropriate) all analyses; these were met. Results are reported for final set of individual predictors/models only.

A few considerations regarding the way in which results are reported and to be interpreted are worthy of note. First, results are presented as an estimate of an effect size, followed by an exact probability (a *p* value) and a 95% confidence interval (CI). Effect sizes indicate the magnitude or size of the association observed whereas *p* values indicate whether an effect is nil. CIs provide likely boundaries for the lower and upper limits of the true effect size in the population. A 95% CI that begins (or ends) precisely at zero would yield a *p* value of .05 and a 99% CI that begins (or ends) precisely at zero would yield a *p* value of .01. However, unlike a *p* value which supports a dichotomous decision of whether there is an effect, the CI gives a sense of both the precision of the estimate (the narrower, the more precise), as well as its extremity (upper and lower limits).

In summary, following the estimation, i.e., effect size approach, we provide an index of the effect size, followed by an exact probability and a 95% CI but do not make statements about statistical significance[1].

[1] When interpreting indices of effect size, guidelines regarding the magnitude of those are as follows: For multiple multivariate linear regression analyses, in case of η_p^2, a small effect ≤.02, medium ≤.13, and large effect ≤.26 (http://imaging.mrc-cbu.cam.ac.uk/statswiki/FAQ/effectSize). β coefficients (in *SD* units) can be compared to assess the relative strength of predictors, e.g., "1 *SD* decrease/increase in X would yield a β *SD* decrease/increase in Y". Some argue βs can be interpreted as weak ≤0.2, moderate between 0.2 and 0.5, strong if >0.5 (Acock, 2008; p.272). For cox regression analyses, χ^2 or the likelihood chi-square statistic is an index of overall model fit, calculated by comparing the deviance (-2*log likelihood) of the obtained model, with all predictors and covariates specified, against the model with all such variables dropped. In case of exp(β), a value >1, means that there is

376 The datasets generated and/or analysed during the current study are available from the
377 corresponding author upon reasonable request.

378 **Results**

379 **Descriptive statistics**

380 For data on individual dogs across variables of interest, see Tables 1 and 2. For
381 descriptive statistics, including *M, SE,* 95% confidence intervals (CI) and range, see Table 3.

Table 1

Data on Individual Dogs Across Demographic and Rating Scale Variables on the owner-report Dog-ADHD Rating Scale (Lit et al., 2010; Vas et al., 2007) and owner-report the Dog Personality Questionnaire (Jones, 2009).

Name	IA	HI	Ext	Coop	Conf	Open	Consc	Age	Sex	Training status
Akina	2	10	28	28	29	32	34	2	Female	Advanced
Alma	2	6	29	39	34	34	37	8	Female	Basic
Barkus	7	10	29	42	31	37	28	5	Male	Basic
Bingó	6	8	34	36	29	39	37	1	Male	Intermediate
Bogyó	5	3	18	40	34	30	33	3	Female	Intermediate
Borisz	5	9	30	39	31	38	29	5	Male	Basic
Demi	1	9	28	39	29	36	34	3	Female	Basic
Dolores	7	5	28	34	27	36	28	3	Female	Advanced
Döme	2	10	31	40	29	38	35	4	Male	Basic
Joker	5	8	27	28	21	35	33	2	Male	Advanced
Kitty	2	5	27	43	26	38	37	1	Female	None
Kópé	6	11	28	32	31	30	33	9	Male	Basic
Leia	6	4	27	36	23	33	36	4	Female	Intermediate
Lili	3	4	29	34	29	38	33	3	Female	Basic
Liza	4	14	33	31	22	39	35	4	Female	Advanced
Lizi	5	6	33	32	27	36	34	6	Female	Advanced
Lord	3	0	17	24	37	22	36	10	Male	None
Lucky	2	6	27	41	31	33	31	10	Male	Basic
Mara	6	11	32	38	23	38	33	2	Female	Advanced
Molly	3	6	35	42	24	34	33	4	Female	Intermediate
Monty	3	5	29	33	28	34	35	7	Male	None
Öre	7	16	36	30	34	34	33	2	Male	None
Pille	5	11	35	40	30	35	34	1	Female	None
Rozi	0	2	26	36	30	39	45	8	Female	Basic
Rynn	3	9	27	40	28	33	29	2	Female	Basic

greater probability of experiencing the terminal event and a value <1 means that an increase in one unit for that variable will decrease the probability of experiencing an end point throughout the observation period.

Simon	3	4	30	44	37	37	36	3	Male	None
Vackor	5	19	38	33	18	36	32	9	Male	None
Zajec	8	12	33	39	28	39	29	3	Female	Basic
Zebulon	7	9	34	34	30	33	30	9	Male	Basic

Note. Ext = Extraversion, Coop = Cooperation, Conf = Confidence, Open = Openness, Consc = Conscientiousness

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Table 2

Data on Individual Dogs Across the canine Go/NoGo Behavioural Inhibition Test Performance Variables.

Name	Omission error percent	Commission error percent	Correct "go" latency (ms)	Commission error latency (ms)
Akina	4.17	37.50	895.26	1046.50
Alma	0.00	37.50	717.54	875.17
Barkus	12.50	37.50	877.43	848.00
Bingó	0.00	31.25	766.75	1123.80
Bogyó	12.50	18.75	1491.90	1659.67
Borisz	4.17	12.50	1608.35	2065.00
Demi	16.67	0.00	1574.70	3000.00
Dolores	0.00	0.00	1434.21	3000.00
Döme	33.33	12.50	753.38	1502.00
Joker	0.00	18.75	953.67	1739.00
Kitty	0.00	25.00	782.25	1313.25
Kópé	0.00	50.00	841.08	1354.63
Leia	29.17	6.25	2250.59	2804.00
Lili	16.67	6.25	1049.45	865.00
Liza	45.83	12.50	1251.23	538.50
Lizi	4.17	68.75	741.70	665.73
Lord	8.33	18.75	939.41	936.33
Lucky	0.00	12.50	1110.54	1101.00
Mara	0.00	0.00	1002.96	3000.00
Molly	8.33	31.25	926.86	788.00
Monty	25.00	6.25	1882.50	2416.00
Öre	12.50	56.25	1199.05	635.44
Pille	16.67	6.25	1218.00	2720.00
Rozi	4.17	0.00	1620.35	3000.00
Rynn	12.50	12.50	1179.38	1851.00
Simon	8.33	6.25	1001.86	1827.00
Vackor	15.00	60.00	1463.82	1376.67
Zajec	0.00	0.00	1016.25	3000.00
Zebulon	8.33	12.50	858.00	1154.00

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Table 3

Descriptive Statistics on Study Variables

	range	min	max	*M* (95%CI)
Omission error %	45.83	.00	45.83	10.29 (6.58; 14.60)
Commission error %	68.75	.00	68.75	20.60 (13.79; 27.93)
Correct "go" latency (ms)	1533.05	717.54	2250.59	1152.02 (1022.36; 1294.52)
Commission error latency (ms)	2461.50	538.50	3000.00	1662.27 (1343.28; 1981.32)
IA	8	0	8	4.24 (3.52; 5.00)
HI	19	0	19	8.00 (6.62; 9.52)
Confidence	19	18	37	28.62 (27.04; 30.17)
Conscientiousness	17	28	45	33.52 (32.31; 34.83)
Cooperation	20	24	44	36.10 (34.24; 37.93)
Extraversion	21	17	38	29.59 (27.90; 31.07)
Openness	17	22	39	35.03 (33.69; 36.35)
Age	9	1	10	4.59 (3.59; 5.66)

Note. The conscientiousness subscale had acceptable but low internal consistency; all corresponding data should be interpreted with caution.

Errors

The omnibus model with H/I predicting omission and commission error percent was significant, $F(2,26) = 3.38$, $p = .049$ ($\eta_p^2 = .21$; a large effect, Watson, 2016). This effect was driven by greater H/I associated with greater commission error percent, $\beta = 1.72$, $p = .047$ (SE = 0.83; 95% CIs [0.02; 3.42]) (Figure 2). Differences in H/I accounted for 14% of the variance in the outcome ($\eta_p^2 = .14$; a medium-large effect).

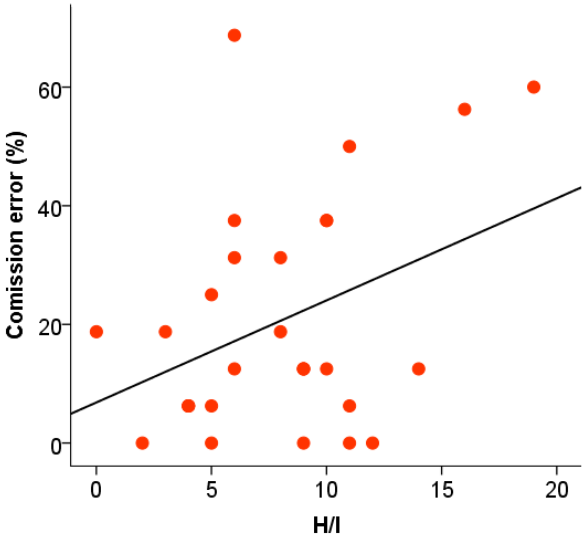

Figure 2. *Greater owner-rated H/I is associated with a greater proportion of commission errors on the Go-No/Go task.*

Note. The fitted regression lines are default SPSS fitted lines representing the trend of the data, with the slope corresponding to the unstandardized regression coefficient *b* of a linear regression equation, where Y = *a* (i.e., intercept) + *b*X (in this case, y=6.83+1.72*x).

Response times

Training status, confidence, openness, and extraversion jointly predicted average latency to correct "go" responses ($\chi^2(6) = 10.57$, $p = 0.103$). Dogs were *less likely* to have an earlier correct "go" response if they had none compared to basic training (exp(β) = 0.12, p = 0.012 [0.02; 0.62]) (but the intermediate to none or the advanced to none difference was not significant) or had lower scores on openness (exp(β) = 0.83, p = 0.062 [0.69; 1.01]). Dogs were *more likely* to have an earlier correct "go" response if they were higher on: confidence (exp(β) = 1.14, p = 0.061 [0.99; 1.30]) or extraversion (exp(β) = 1.20, p = 0.013 [1.04; 1.38]).

Training status, sex, confidence, openness, and extraversion jointly predicted average latency to commission errors ($\chi^2(6) = 12.87$, $p = 0.065$). Dogs were *less likely* to have an earlier commission error (i.e., poked) if they had none compared to basic training (exp(β) = 0.15, p = 0.044 [0.02; 0.95]) (but the intermediate to none or the advanced to none difference was not significant). Dogs were also *less likely* to have an earlier commission error if they had lower scores on: openness (exp(β) = 0.75, p = 0.005 [0.62; 0.92]) or on IA (exp(β) = 0.76, p = 0.049 [0.58; 1.00]). Dogs were *more likely* to have an earlier commission error if they were female (exp(β) = 2.96, p = 0.043 [1.03; 8.51]) or had higher scores on confidence (exp(β) = 1.12, p = 0.094 [0.98; 1.27]) or extraversion (exp(β) = 1.29, p = 0.005 [1.08; 1.53]).

Discussion

We examined whether differences in dogs' behavioural inhibition indexed by performance on a self-developed touchscreen Go/No-Go paradigm is related to differences in their owner-rated inattention (IA) and hyperactivity/impulsivity (H/I) levels, accounting for relevant third variables. Results indicated a unique association between H/I and commission errors (the proportion of commission errors relative to the total number of "no-go" stimuli) as well as

associations between latency to correct "go" responses *and* to commission errors with training status and personality. Results further indicated a relationship between latency to commission errors and IA (shorter latency was related to greater IA).

Contrary to human data, IA was not related to error rate. However, consistent with such data, H/I uniquely predicted commission error rate – evidence for convergent validity of the behavioural paradigm and the rating scale. In addition, these findings are also evidence for discriminant validity of the behavioural paradigm and the rating scale in dogs (albeit to a lesser extent), as omission errors similarly correlate less with H/I and commission errors correlate less with IA in humans (Bezdjian et al., 2009; Trommer et al., 1988).

Relative to no prior training, dogs with basic training responded faster, regardless of accuracy (both correct "go" and commission errors). This effect did not hold when comparing dogs with no prior training to dogs with any of the higher levels of training. An explanatory hypothesis is that our sample was not large enough or that we did not have sufficiently fine-grained distinctions between training levels to detect differences between no prior training and the higher levels of training. Another potential explanation is that differences between no and basic training may manifest in simpler behavioural differences, such as response speed, but differences between no and more advanced training may manifest in higher-level skills, such response speed *and* accuracy. Interestingly, in humans, athletes, relative to non-athletes (e.g., Chan, Wong, Liu, Yu, & Yan, 2011), exhibit faster response latencies and fewer commission errors on Go/No-go tasks. The observed differences between no and basic training may be comparable to those observed between non-athletes and athletes, with "basic training" being comparable to sports, as argued by others (Helton, Feltovich, & Velkey, 2009).

Greater confidence and extraversion were associated with smaller latency to correct "go" responses and commission errors, similar to training status, regardless of accuracy. Humans scoring higher on neuroticism (opposite of confidence) do not exhibit differences in their

reaction time but exhibit greater variability in this regard across tasks and time (Robinson & Tamir, 2005). Results parallel human data indicating extraversion is associated with faster movement- and reaction time (Stahl & Rammsayer, 2007). Following these patterns, openness was associated with greater latency to correct "go" responses and commission errors. Although in humans there is a similar negative association between openness and reaction time (Wainwright, Wright, Luciano, Geffen, & Martin, 2008), these associations are small and not well-replicated (Graham & Lachman, 2012).

Interestingly, dogs were *more likely* to have an earlier commission error if they were female. Data on relevant human sex differences are mixed: e.g., on an equiprobable auditory Go/No-Go task, there was no difference between men and women in reaction times (Melynyte, Ruksenas, & Griskova-Bulanova, 2017) whereas on a cognitive inhibition/interference control task, men's responses were consistently slower (Mekarski, Cutmore, & Suboski, 1996).

Finally, IA was associated with latency to commission errors (i.e., lower IA was related to greater latency to commission errors) but not to correct "go" responses and H/I was not associated with either latency variables. These results are inconsistent with human findings suggesting that youth with primary IA tend to respond more cautiously and slowly (including in Go/No-Go tasks) whereas those with combined IA and H/I tend to have a hasty, impulsive response style (Derefinko et al., 2008; Trommer et al., 1988; but see, for an exception Bezdjian et al., 2009).

Limitations and Future Directions

These results will need replication, ultimately with larger samples. Additional aspects of behavioural disinhibition beyond delay of gratification (Riemer et al., 2014; Wright et al., 2012), such as action cancellation, should be examined. Modifications to rating scale measures of dog ADHD-B/S may be necessary given acceptable but insufficiently stable psychometric properties across samples (including barely acceptable internal consistency of the IA subscale

in the current sample and data obtained by Lit et al., 2010; Vas et al., 2007). While humans receive little to no training prior to Go/No-Go measurements, dogs' training for the test may have reduced errors and response times, potentially explaining null effects. A more difficult canine Go/No-Go test may help address reduced variability. To ensure that dogs are not trained in the same setting where they are tested – and thus increase human-dog comparability, an automatic Go/No-Go test for the home environment may be developed. Inconsistences between human and dog data may also reflect that some of the examined relations are not comparable across humans and dogs. These alternative hypotheses will need disentangling, for better understanding of the boundaries of the canine model of the relationship of human behavioural inhibition and ADHD.

Nevertheless, rodent studies of behavioural inhibition and/or go/no-go performance validate some biological or genetic modification, e.g., differences among mouse (Gubner, Wilhelm, Phillips, & Mitchell, 2010; Majdak et al., 2016; Oakeshott et al., 2013) or rat strains (Anker, Zlebnik, Gliddon, & Carroll, 2009) or as a result of lesions (Eagle, Baunez, et al., 2008) using differences in task performance. Although fruitful in validating a model with regard to associations between biological and behavioural aspects (i.e., predictive validity) (Sagvolden et al., 2005), these tests do not demonstrate an expected convergence and divergence across different indices of the behavioural phenotype, such as between differences in behavioural inhibition and ADHD-B/S. Conversely, as noted, dogs naturally exhibit genetic polymorphisms and individual differences relevant to inhibition and ADHD-B/S and we could test and find support for evidence of convergent validity of behavioural inhibition and IA and H/I in dogs. With this established, questions that cannot be addressed with rodents (e.g., due to need for need for fluid and/or food restriction and restricted physical and social environment not shared with humans) and a host of additional hypotheses can be tested with dogs, including ones relevant to modelling functional impairment and treatment response in ADHD.

Our findings are in line with the growing body of work evincing the dog is an ideal animal model of complex human processes, not only with regard to individual differences in behavioral/neuropsychological (i.e., Go/No-Go performance reflecting behavioral inhibition) and cognitive (e.g., ADHD-B/S)/temperamental or personality variables but also to the *relationship* between those (e.g., H/I associated with commission errors). These results thus suggest that the phenotypic variability in these characteristics in dogs is analogous to that observed in humans, lending support to the dog's potential for ultimately modelling the genotypic or biological variability that underlies this phenotypic variability in behavioral inhibition or ADHD.

In summary, the current study is the first attempt at examining the relationship between behavioural inhibition and individual differences in IA and H/I in domestic dogs. Our findings add to the pertinent literature by extending the dog as an animal model of human behaviour and cognition to behavioural inhibition and ADHD-like behaviours and symptoms.

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